May 10, 2012

Bioremediation - How microbes are used to clean up DOD Installations

Overview

- Who is Solutions-IES?
- Brief History of Remediation Technology
- Bioremediation basics
- Enhanced Reductive Dechlorination
- Project Examples
- New Technologies & Emerging Contaminants

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Who is Solutions-IES, Inc.?

Full service environmental company

- Formed in Raleigh in 1999
- Licensed Engineering and Geology firm
- Woman Owned Small Business (WOSB)
  - Certified 8(a) DB firm
  - North Carolina HUB
- DCAA approved accounting system
- Serving DoD and private industry
- Providing both traditional and innovative solutions

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Historical Perspective

(1980s to 2000)

- Pump & Treat
- Dig & Haul
  - Energy & Capital intensive
  - Transfer contamination between medium
  - Difficult to reach closure

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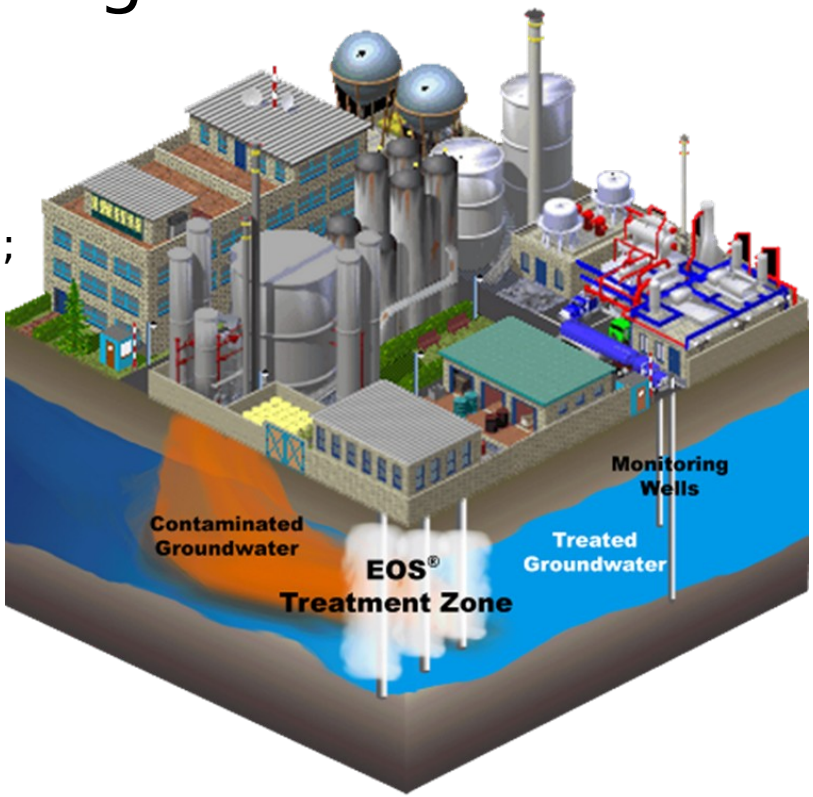
Historical Perspective

(mid-1990s to mid-2000s)

- In Situ Treatment Technologies
  - Physical:
    - Air Sparge;
    - Soil Vacuum Extraction (SVE);
    - In Situ Chemical Oxidation (ISCO);
    - Fe0 walls
  - Biological:
    - Biosparge;
    - Biovent;
    - Oxygen and Nutrient Addition;
    - Substrate Addition;
    - Biobarriers



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Current Perspective

(mid-2000s to now)

- Optimization
- Sustainability
- Emerging Contaminants
  - Chlordane
  - 1,4-Dioxane
  - PFOS/PFOA
  - Low Permeability Zones

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Typical Remediation Costs

- Surfactant Co-solvent Flushing* $385/yd^3
- Chemical Oxidation* $125/yd^3
- Thermal Treatment* $88/yd^3
- Stabilization $15-80/yd^3
- Dig and Haul $4-10/yd^3 + T&D
- Pump & Treat ∞
- **Enhanced Bioremediation* $29/yd^3**

*From: McDade, Travis and Newell, 2005

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In Situ Bioremediation

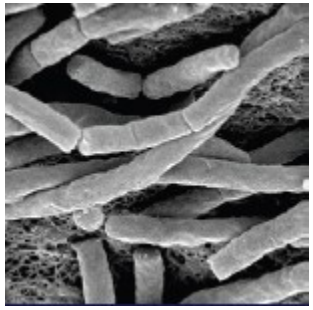
In Situ

In Place

Bio

Microbial

Remediation



Biological agents (bacteria, fungi, plants, or their enzymes) used to clean up pollution in the environment.

Reference: Lisa Alvarez-Cohen, Civil and Environmental Engineering
University of California, Berkeley, Earth Science Division, LBNL

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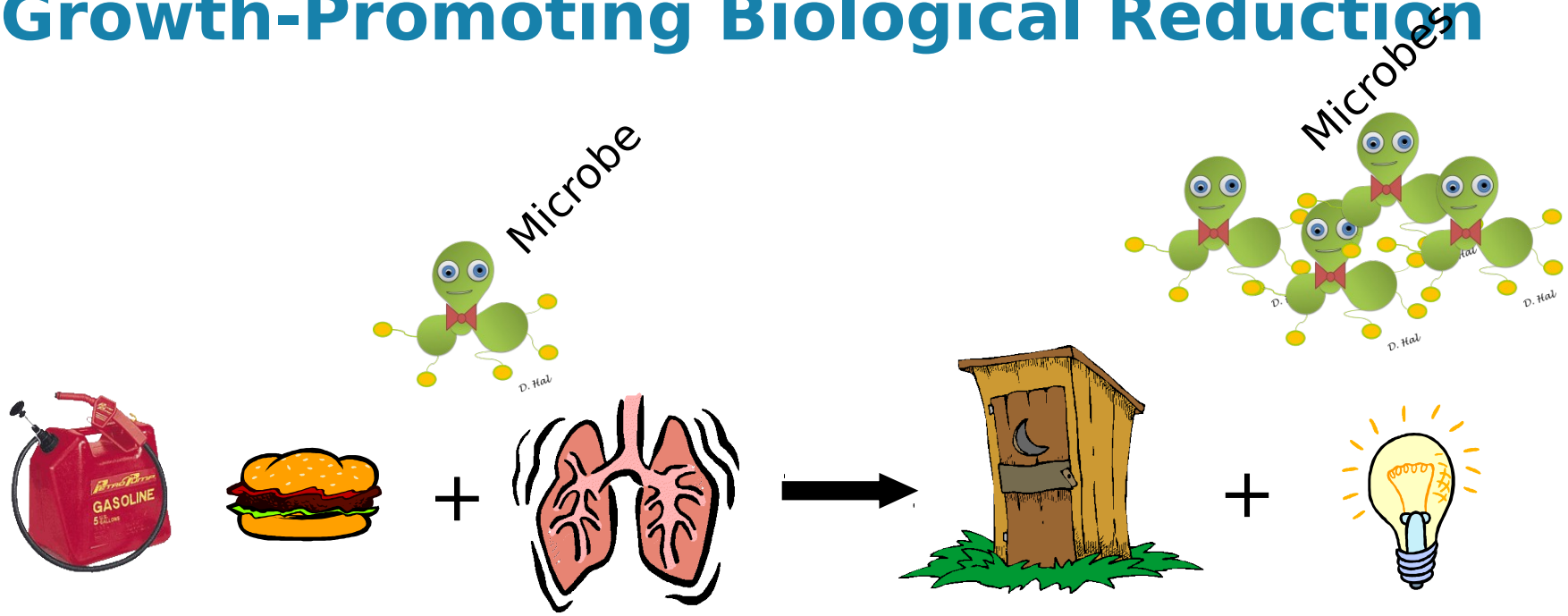
How Does It Work?

Growth-Promoting Biological Reduction



Electron Donor (Food)

Electron Acceptor (something to breathe) [O_2, NO_3^-, SO_4^{2-}, TCE, etc.]

Waste Products [CO_2, N_2, FeS_2, Cl^-]

Energy

(Drawing Modified from AFCEE and Wiedemeier)

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Applying *In Situ* Bioremediation

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Anaerobic Bioremediation Target Contaminants

- Chlorinated Organics
  - Ethenes (PCE, TCE)
  - Ethanes (TCA)
  - Methanes (CT)
- Petroleum Hydrocarbons
  - Aromatic Hydrocarbons
  - Total Petroleum Hydrocarbons (TPH)
  - Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX)
  - Methyl tert-butyl ether (MTBE)
  - tert-Butyl Alcohol (TBA)
- Nitrate, Perchlorate, Chromate
- Explosives (TNT, RDX, HMX)
- Acid Mine Drainage

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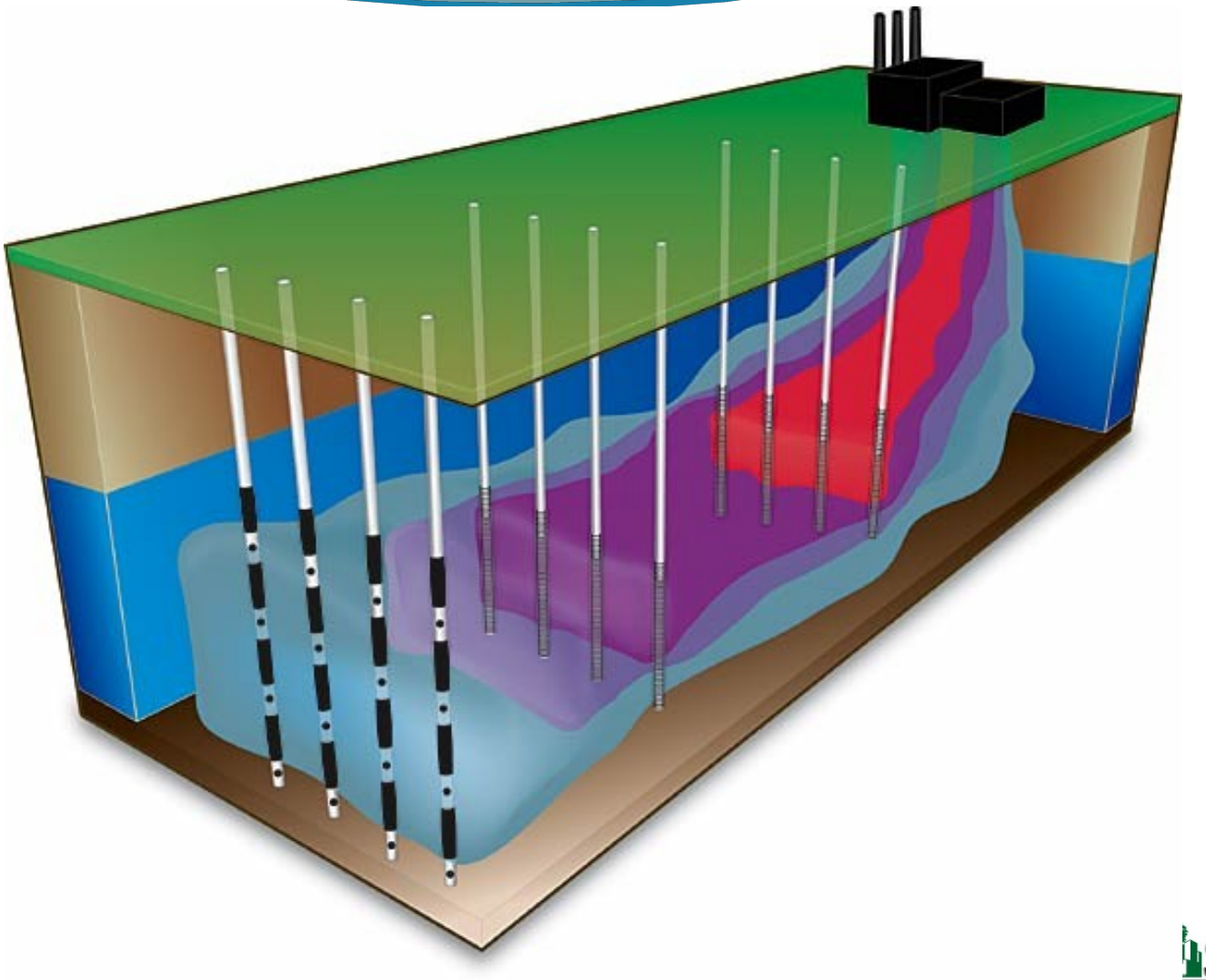
How Does It Work?



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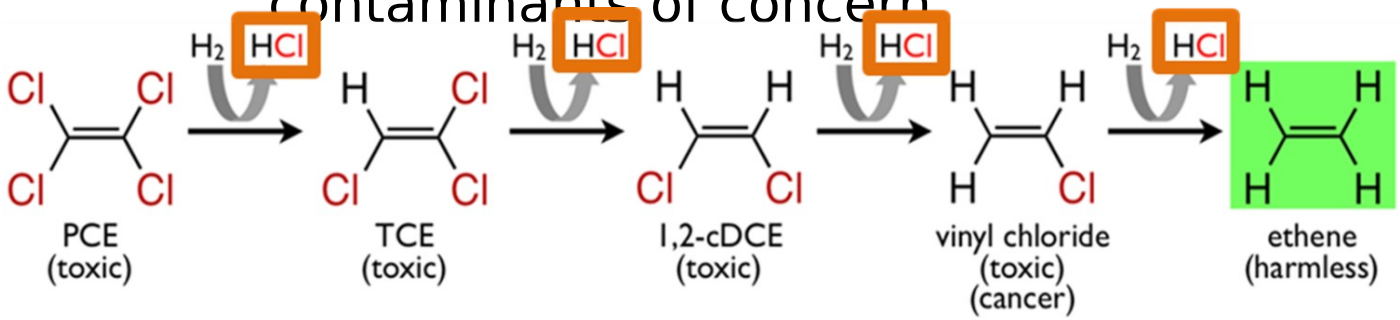
Enhanced Reductive Dechlorination

- *In Situ* anaerobic bioremediation
- Injected into contaminated aquifer
- Source zone and/or PRB treatment
- The organic substrate:
  - Develops an anaerobic and reducing treatment zone
  - Generates hydrogen through fermentation reactions
  - Stimulates microbial growth and metabolism of contaminants of concern



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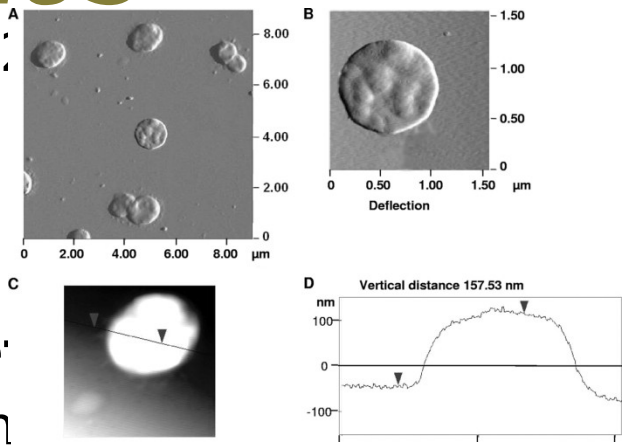
Dehalococcoides ethenogenes

- Multiple strains (BAV1, 195, VS, MB, FL
- **Obligate anaerobe**
- Disc-shaped; spontaneous motility
- Prefers neutral pH environment
- **Complete dechlorination to VC & e**
- Grows slowly; prefers life in consortium
- Uses acetate for C source;
  H_2 as electron donor
- Can use chloroethenes, chlorophenols and PCBs as terminal electron acceptors.



Cheng D , He J Appl. Environ. Microbiol. 2009; doi:10.1128/AEM.00767-09

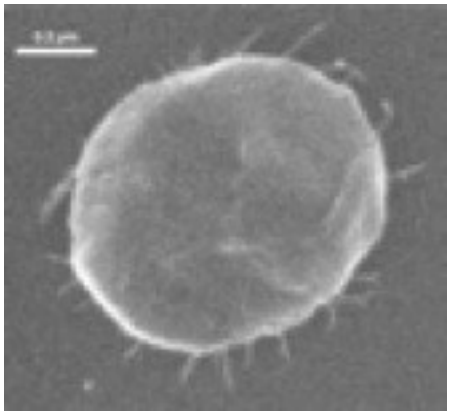


Photo of BAV1 – courtesy of Dr. Frank Loeffler

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AEC
Tarheel Army Missile Plant
Burlington, NC

In Situ Bioremediation of TCE

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Tarheel Army Missile Plant

1944 – 1992 GOCO Facility

- 1993 Soil and groundwater contamination discovered (BTEX and TCE)
- 1995 AS/SVE placed in operation
- 1999 P&T initiated NW corner
- 2003 Guaranteed fixed price bids from multiple vendors
- 2004 Army selects Solutions-IES to perform work
- 2004 AS/SVE system turned off and Solutions-IES begins EOS® injection

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Costs (in $1,000)

Vendor	Process - Reagent	Pilot (GFP)	Full (Est.)	Total
NA	MNA	0	250	250
Solutions-IES	ERD - EOS	256	728	984
Magnus pHA	Cometabolic- C_3H_8	321	894	1,215
Cl-Solutions	Cometabolic- Cl-Out	373	1,141	1,515
Arcadis	ERD - molasses	339	1,456	1,795
Electro-Petroleum	AS with CO_2	291	1,763	2,054

TAMP Site Conditions

Source area 100’ x 100’

Existing AS/SVE System

- Oxidative conditions

Chlorinated Solvents

- 2 – 4 mg/L

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Regulatory Challenges

Groundwater Reinjection

- Recovered groundwater is a “waste”
- Innovative below-ground reinjection system

Bioaugmentation

- First approved use of DHC bioaugmentation in NC

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TAMP - Summary

- EOS® effectively distributed throughout treatment area
- Quickly established favorable geochemistry for reductive dechlorination
- TCE reduced to below detection (<1.0 µg/L) in monitor wells in treatment area
- **Remedial goals met within 6 months** of injection
- **US Army has sold property!**
- Site has been redeveloped as commercial / office complex

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NAVFAC Southeast
NAS Pensacola
SWMU 1 – WWTP

In Situ Bioremediation of TCE in a Sulfate-Rich Acidic Aquifer

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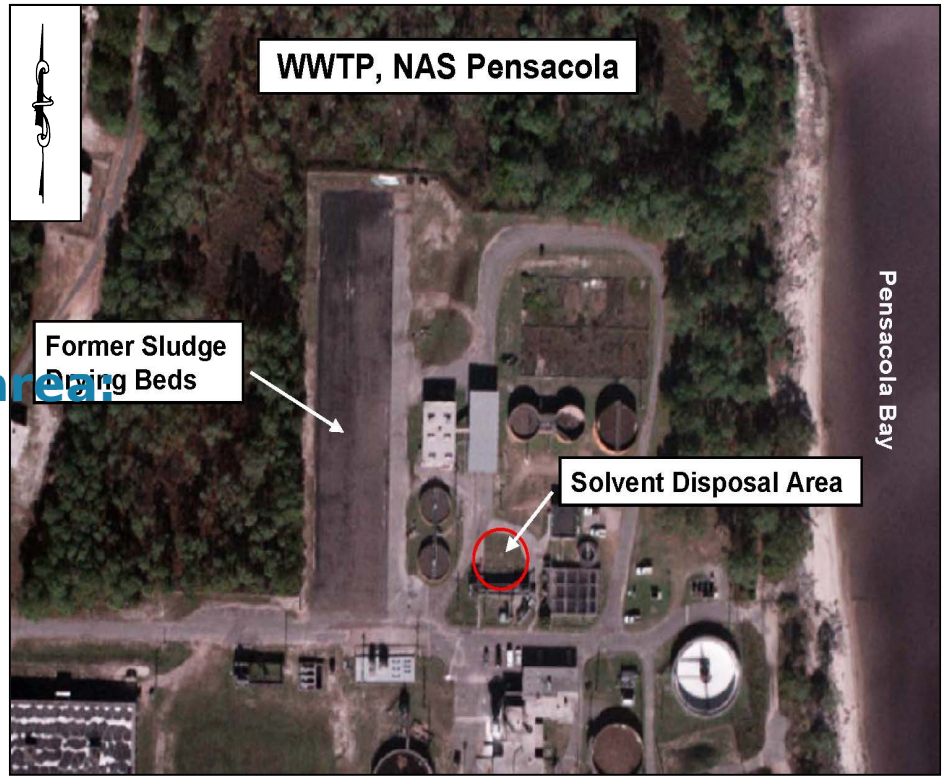
Site History

- **Former WWTP (SWMU 1),**
- **TCE plume with DNAPL source**
- **Sulfuric acid spill 1983**
- **Concentrations in the source area:**
  pH – 3.5
  TCE – 18,000 µg/L
- **Remedial activities:**
  P&T 1986-1997
  ISCO w/Fenton's 1998-1999
  MNA for downgradient plume
- **Further treatment required**



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Remediation Plan

- **AquaBupH™ to promote *in situ* bioremediation**
  Emulsified oil substrate
  Alkaline solids to adjust pH
  Nutrients
- **Pilot Study – 2008**
  2 injections in source area
- **Full-Scale – 2010**
  2 rounds of injections

AquaBupH™ is a licensed product of EOS Remediation, LLC.; Raleigh, NC

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pH affects on *Dehalococcoides sp.*

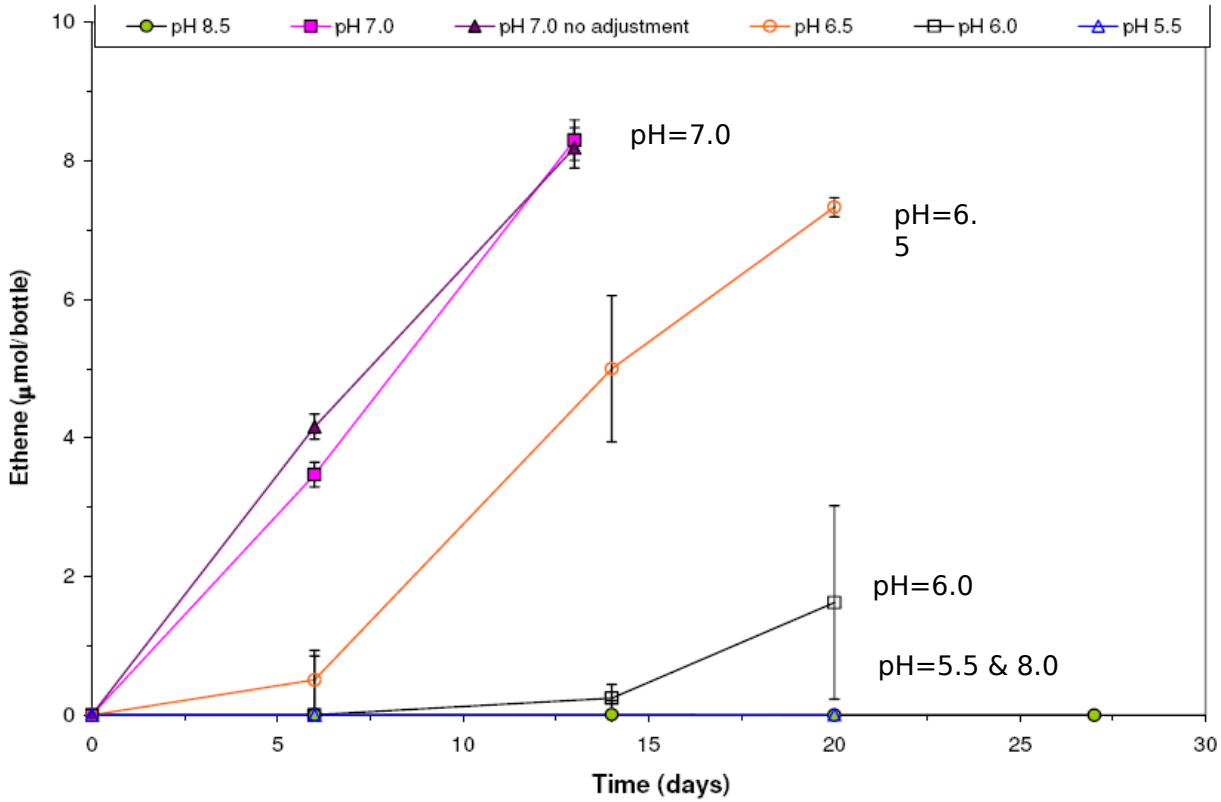

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Figure 4.172 Comparison of pH effect on ethene production based on the first PCE and TCE addition at all pH levels (averages of triplicates). Error bars represent ± one standard deviation.

Ashley Eaddy, 2008. *Scale-Up and Characterization of an Enrichment Culture for Bioaugmentation of the P-Area Chlorinated Ethene Plume at the Savannah River Site*. M.S. Thesis, Clemson University.

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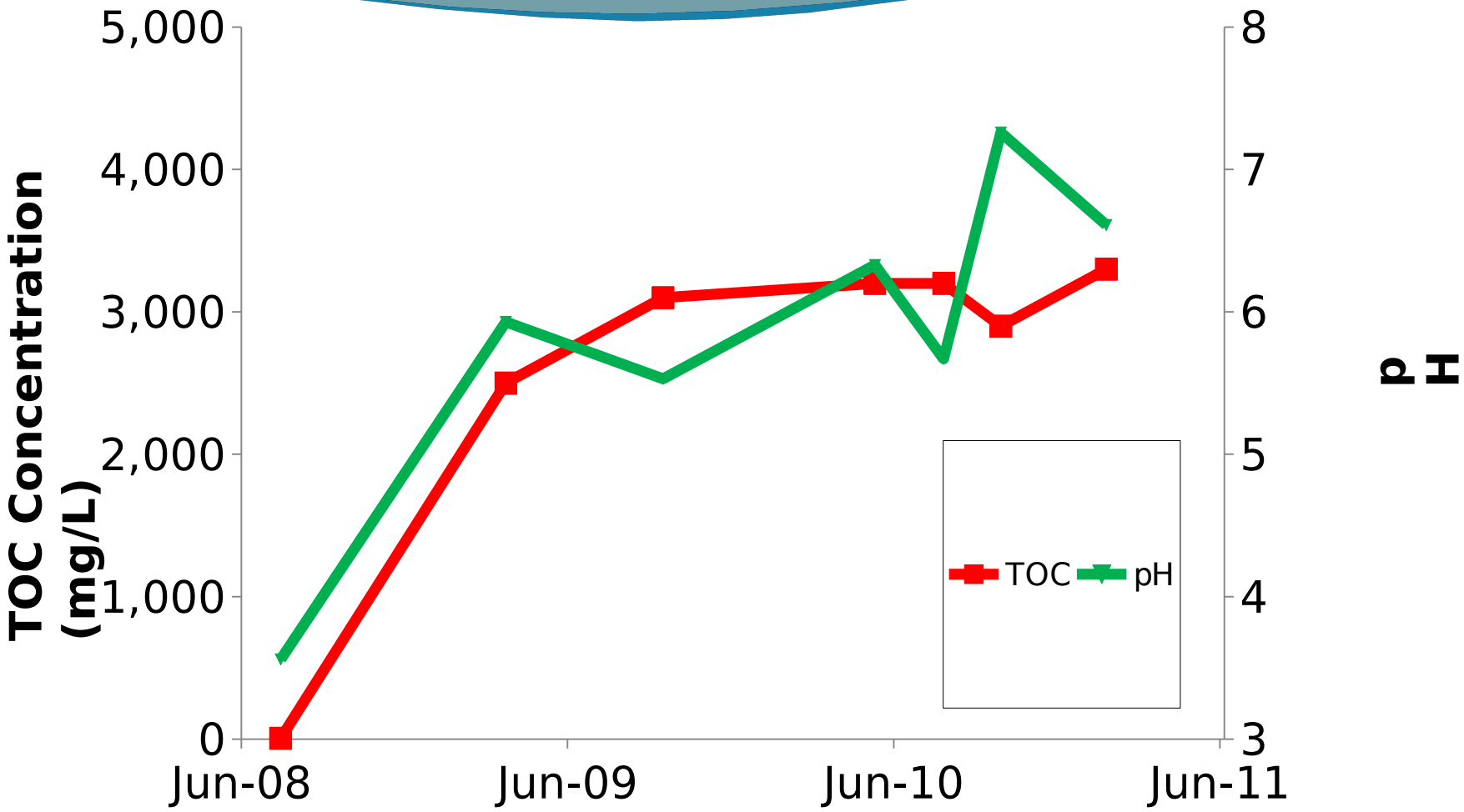
Total Organic Carbon & pH Results



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Emerging Contaminants & New Technologies

Soil Remediation

- VOS™
- Range Sustainability
- Chlordane

U.S. AIR FORCE

GW Remediation

- EAS™
- MNA for perchlorate remediation

ESTCP

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA ·

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Summary

- Bioremediation
  - Wide range of applicability
  - One of many remediation o
  - Sustainable
  - Cost-effective
- On-going Research
  - Micro-Biological Tools (MBTs
  - Emerging Contaminants
  - Optimization

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